I. INTRODUCTION

The 1999 Biological Opinion (BO) on the Klamath Project Operations (NMFS 1999) identified that flow change (ramping) at Iron Gate Dam (IGD) may be a potential cause of fish stranding downstream in the Klamath River. Article 2 of the Terms and Conditions in the BO states:

> " (U.S. Bureau of Reclamation - BOR) in cooperation with PacifiCorp, provide a brief report summarizing how Project and PacifiCorp operations affect Klamath River stage height changes (within the zone of IGD influence), and the implications regarding possible coho salmon stranding. The report will include, but is not limited to, a description of how ramping operations occur at IGD and the resulting Klamath River stage changes between IGD and the Shasta River, and an inventory of potential fish stranding areas related to river stage changes."

Recognizing the relationship between BOR and PacifiCorp operations on the Klamath River system, PacifiCorp agreed to take the lead on this report given that they are the entity who owns and operates Iron Gate Dam.

On August 31, 1999, PacifiCorp conducted a meeting to discuss with stakeholders their issues and concerns regarding ramp rates. Additionally there was discussion about the types of information to be included in the ramp rate study report.

It was generally agreed that the time frame in which the study was to be completed was insufficient to allow an empirical, on-the-ground study to determine the extent of potential ramping effects. Instead, the group decided to use existing data to address the ramp rate issues identified in the BO (see meeting summary in Appendix 1).

The following report summarizes available information on ramping at Iron Gate. In addition, a hydrodynamic model was used to examine potential stage change, travel times, and flow attenuation.

<u>Objectives</u>:

As was agreed upon at the August meeting, the objectives of this report are to use existing data to:

1. Describe project operations and historic ramping quantitatively.
2. Demonstrate, with data and models, how water levels fluctuate as a function of time and distance downstream.
3. Estimate the downstream extent of the influence of ramping.

4. Quantify the water level and discharge changes that occurred in the spring of 1998, in relation to fry stranding at the Tree of Heaven campground.
5. Discuss general agency guidelines, and their relevance to Iron Gate operations.
6. Identify data gaps.
7. Identify areas of potential stranding habitat based on agency input.

II. CURRENT OPERATIONS

Iron Gate Dam, located at RM 190 on the Klamath River, is the focus of this report (Figure 1). A complete description of the operations of the PacifiCorp facilities associated with ramping at Iron Gate and upstream is found in Appendix 2. The operations can be briefly summarized as follows.

The Iron Gate facility has storage of only 3790 acre-feet, and a turbine capacity of 1735 cfs. Inflow from the hatchery and from Bogus Creek combine to make this flow about 1800 cfs at the Iron Gate gaging station below the dam. At flows below about 1735 cfs, the Iron Gate turbine can be closely regulated to control ramping rates; typically, PacifiCorp has been able to limit ramping to less than 25 cfs per hour over this range (Based on analysis of Iron Gate gage flows, 1993-1998).

At flows above 1735 cfs, Iron Gate Dam spills, and has little to no control over downstream flows. The Copco projects, 8 miles upstream, can control flows up to 3200 cfs through their turbines. The control of flow below Iron Gate is more complicated over this flow range (1735-3200 cfs at the gage), because it is affected by the Copco turbine flow, reservoir retention time, and tributary flow between Copco and Iron Gate.

At flow above 3200 cfs, flows at Copco can be controlled only via 13 sets of spill gates 11 of which are manually operated. The margin of error in operating these gates is large, and probably not an effective means of ramping regulation.

> In summary, PacifiCorp can control ramping very closely at flows below 1735 cfs, moderately between 1735 and 3200 cfs, and in a very limited fashion above 3200 cfs.

PacifiCorp has a license that allows flow fluctuation at Iron Gate of up to 250 cfs per hour, or 3 inches per hour, whichever is less. These rates have rarely been approached in practice. Nevertheless, resource agencies are concerned that rapid downramping or large reductions in total flow over 24 hours, have the potential to be detrimental to salmonid populations. For this reason, it is important to present historical data, and estimate the potential effects of ramping downstream.

III. GENERAL EFFECTS OF RAMPING.

Hunter (1992) provided a comprehensive summary of the effects of ramping on salmonids. Stranding, defined as the separation of fish from flowing water as a result of declining river stage, is one of the major impacts of ramping. Several studies were cited in his report, documenting stranding of juvenile salmonids in gravel bars, side channels, and potholes. Stranding is much more likely to occur in areas with side channels and low-gradient bars vs. a single channel with steep banks. The author pointed out that present methods for estimating stranding losses as a function of flow change are inexact. Hunter's ramping guidelines (p.23 of his report), drawn from his literature review, have been adopted with some modifications by resource agencies in the Northwest (Table 1).

IV. GEOMORPHIC OVERVIEW OF THE KLAMATH RIVER

Ayres Associates recently conducted a geomorphic study of the Klamath River below Iron Gate Dam for the U.S. Fish and Wildlife Service in Yreka, CA (Ayres, 1999). The study does not quantify the amount of the river where side channels and gravel bars exist but it generally states where a majority of this habitat occurs. Most of the flow splits were identified to be downstream of the Scott River (RM 143). "Moving upstream, the bars are lower and become coarser-grained in relation to the rapid decrease in channel and valley width, increase in channel slope, and local contributions of coarse sediment from debris fans, landslides and debris avalanches along the channel."

The Ayres report also states that extensive instream mining has contributed significantly to the past and present morphology of the river. In many cases where gravel mining on the Klamath River has occurred, streamside tailings and spoil piles were created. "The most heavily mined areas (are) upstream of the confluence of the Scott River (RM 143)." However, upstream of the Shasta River (RM 176) to RM 181 the "Klamath River is confined by a narrow canyon with no significant naturally formed bars." And from RM 181 to Iron Gate Dam (RM 190) "there are few bars of limited extent throughout the reach."

T. Shaw (unpublished) mapped habitat types in the Klamath below IGD. His study did not include specific identification of stranding areas. Gravel and cobble bars were not enumerated; however, all side channels were located and measured. According to this study, side channels make up 6.7% (by length) of the first 70 miles below IGD. Side channels are less common (4.2%) in the 14 miles between IGD and the Shasta River. Figure 2 shows the locations and lengths of all side channels in the 70 mile reach.

It appears that, based on these two studies, potential stranding habitat is not prevalent in the 14 miles between IGD and the Shasta River. It becomes more abundant, in terms of both side channels and bars, downstream.

V. HISTORY OF RAMPING AT IRON GATE DAM

A) Prior to Iron Gate.

Hanel (1958, unpublished) carried out an empirical study of fish stranding as a function of ramping at Copco Two. Flow at Copco was allowed to change by as much as 9 inches per hour. Relatively few salmonids (though many non-salmonids) were stranded or killed in this test.

Hanel's study is not very relevant to the present-day situation below Iron Gate. The study does indicate that flow changes can cause fish stranding. However, the data are not quantitative in terms of the amount of stranding as a function of different ramping rates. More serious is the fact that the timing of the study, July 14-August 30, was such that few chinook salmon fry or juveniles were present. Finally, the study was done prior to the construction of Iron Gate Dam.

B) PacifiCorp ramping in the 1990's

PacifiCorp's current license allows ramping at Iron Gate of 3 inches, or 250 cfs per hour, whichever is less, except when conditions are beyond its control.

PacifiCorp compiled records of actual ramping rates below Iron Gate from 1993 to mid 1998. These records are from the Iron Gate gage (USGS #11516530) downstream of the dam. When flows were below 1800 cfs at the gage, ramp rates were below 1.0 inch per hour, and below 100 cfs per hour, about 97% of the time. At this same flow range, ramp rates were less than 2 inches per hour about 99% of the time (Figure 3a,3b). When Iron Gate was spilling, at flows above 1800 cfs at the gage, the results (Figure 4a, 4b) were similar. The maximum downramp rate <u>in cfs</u> was higher during spill operations, but this did not translate into a higher frequency of events of 2 inches or more, because the cfs change required to cause a 2 inch stage change increases at higher flows (Table 2).

In summary, PacifiCorp has operated within the current licensed ramping rules virtually all the time since 1993. PacifiCorp has typically ramped at a much more conservative rate than the rules allow.

C) Tree of Heaven event

In the spring of 1998, fish were stranded in 3 pools near the Tree of Heaven Campground (approx. RM 170), concurrent with a flow decrease at Iron Gate. The principal flow decrease was from 4,363 cfs on April 20, to 1,987 cfs on April 23. This was a drop of 2,376 cfs over 72 hours, or an average of about 33 cfs per hour. The maximum rate of change was a drop of about 131 cfs per hour at 0660 hours on April 21 (Iron Gate gage hourly records). The maximum percentage change in a 24-hour period was 3770 to 2612 cfs, a drop of 31%. It should be noted that these flows were all beyond the turbine capacity at Iron Gate, and, for much of the time, beyond the Copco turbine capacity.

On May 1, 1998, three isolated pools across from the Tree of Heaven Campground were sampled for fish rescue by Mike Rode of CDFG at a flow of approximately 2200 cfs at the Iron Gate gage. A total of 738 chinook fry, 7 coho fry, and 1 steelhead fry were found stranded in the three pools combined. (500 individuals of 8 non-salmonid species were also found). The pools are part of an artificial spawning channel built by the U.S. Forest Service in the 1980's.

The actual rate of flow drop at the site in question is not known precisely. This is because no staff gages were in place during the event. Also, the Seiad gage (USGS 11520500, RM 128) information is of little use for this period, because inflow from the Shasta (RM 176), Scott (RM 138), and other tributaries made for a difference between the two gages of 4000 to 5000 cfs, thereby eliminating any opportunity to study attenuation. The rate of change at the campground can be estimated very approximately using results from the hydrodynamic model (see Section VI).

VI. ATTENUATION AND ZONE OF INFLUENCE

A) Pulse flow results

In 1994, PacifiCorp released several 'pulse flows" from Iron Gate Dam. The downramping was done from about 1150 cfs to about 600 cfs. It was very gradual, and prolonged over several days (Table 3). It should be noted that these were unusually low flows, well below the BOR and FERC minimum flows, and due to drought conditions. The up- and downramping was an attempt to move juveniles out of the river during the drought year.

No staff gages were in place downstream of Iron Gate during this time. However, because tributary inflow was relatively low and stable, the effects could be studied by reviewing the hourly readings at the Seiad gage. The downramp at Iron Gate took about 2.5 days to appear at Seiad. At Seiad vs. Iron Gate, the duration of the pulse was about 70% longer, and the maximum flow change per hour was reduced to about 40% of its original magnitude (Table 4).

The limited range of downramping and the lack of staff gages during the exercise make it difficult to discern effects through the reach. However, the fact that the pulse is detectable over 60 miles downstream, and the peak hourly change is still 40% of its original value, does indicate that the zone of influence is relatively long, probably extending to Scott River or beyond at these low flows.

B) Hydrodynamic model

Short of empirical testing, the best analyses of attenuation below Iron Gate stem from a model developed by Mike Deas, a Ph.D. student in the Civil Engineering Department at UC-Davis. This is a hydrodynamic model combining hydraulic relationships, idealized cross-sections, stage-discharge functions, and estimates of tributary inflow. The model takes flows per unit time at Iron Gate, and predicts flows and stage at selected points downstream. The travel time, length of the wave, and maximum rate of change per hour are outputs at the selected points. Specifics of the model can be found in Deas and Orlob (1999).

The model produced results for 10-mile intervals for 5 ramping trials (Table 5). For these trials, inputs from the Shasta and Scott rivers were constants based on average summer values. The model behaved as expected, showing that the wavelength of the downramp increased and the maximum flow change per hour decreased as a function of distance downstream. Results from each trial are discussed below. Figures 5 to 9 illustrate the maximum stage change in inches, as a function of distance downstream, for each of the five trials. *The stage change as modeled is meant as a relative comparison between sites, not as an absolute measure of stage change at a given river location.*

For Trial 1, the starting flow was set at 3000 cfs, and ramping was 250 cfs per hour down to 2000 cfs. The model predicted a stage drop greater than 2 inches per hour for most of the 50-mile reach; the rate exceeded 1 inch per hour for the entire reach (Figure 5).

Trial 2 started at 1800 cfs, with a 100-cfs hourly downramp to 1300 cfs. The model predicted a maximum stage drop of less than 2 inches per hour over most of the reach (Figure 6). Trial 3 also used a 100-cfs hourly downramp, but it started at 1500 cfs and went to 1000 cfs. The results were very similar to Trial 2, but the maximum stage drop was slightly higher at the upstream end of the reach

Trial 4 used the same starting and ending flows as Trial 2 (1800 and 1300 cfs), but the downramp rate was increased to 250 cfs per hour. The stage drop at the starting point was higher compared to Trial 2, but the magnitude declined rapidly downstream until the two trials were about equal at a distance of 30 miles from the dam (Figure 8).

Trial 5 had the same starting and ending flows (1500 and 1000 cfs) as Trial 3, but the downramp rate was 250 cfs per hour. The maximum stage change at the dam was high, but as with Trial 4 it declined rapidly with distance. At a distance of 30 miles from the dam, the maximum stage drop was about equal to that of Trial 3 (Figure 9).

For most of the trials, the 2 inch per hour rate occurred over only the top 10 to 20 miles (Figures 5-9). However, the rate exceeded 1 inch per hour over most of the reach. River distances over which the 1 inch and 2 inch thresholds were exceeded are summarized in Figure 10. Again, these stage changes are more useful for comparing scenarios than for precisely quantifying a river level change at a given location.

The behavior of the model, as displayed in Figures 5-9 is due to several processes (M. Deas, personal communication). The slope, average velocity, depth, and travel time all vary reach-to-reach. Also, tributaries and accretion increase base flow in the downstream direction, which in turn increase velocity and reduce transit time. Finally, the model accounts for some cross section variability; for example the width ranges just over 100 feet to about 150 feet.

C) Trial results at IFIM transect

One potential shortcoming of the hydrodynamic model is that it used idealized, trapezoidal cross sections, rather than real, field-measured cross sections. The differences introduced by this simplification would vary depending on site-specific channel configurations.

A large number of actual cross sections have been measured in the reach of interest. The USFWS has an IFIM study in progress between Iron Gate and Scott River, with about 45 transects measured at 6 locations. These were selected to model representative channel types and fish habitat; no transects were selected specifically to model stranding. Of these, Transect 1 at the Tree of Heaven site is thought to represent a potential stranding area (T. Shaw, pers. comm.).

The cross-sectional shape of IFIM Transect 1 is shown with 3 measured water surface elevations (Figure 11). These measured elevations were used to calculate a stage-discharge relationship over the range 500 to 4000 cfs. The hydrodynamic model was then used to predict the change in cfs per hour at the same river mileage for each of the five trials described above. Finally, the stage-discharge relationship was used to estimate the maximum stage change per hour at the IFIM transect.

The results of the IFIM transect analysis differed markedly from those at the hydrodynamic model cross section near the same river mileage (Figure 12). The maximum change in inches per hour at the IFIM transect is about one-fourth that of the hydrodynamic model transect for each trial.

D) Estimated changes at the IFIM transect during the Tree of Heaven event.

During the Tree of Heaven event, the maximum rate of flow change at Iron Gate was about 130 cfs per hour, at a flow of about 3600 cfs. Based on the hydrodynamic model, and assuming low inflow from tributaries, the maximum rate of change at the IFIM transect would have been about 60% of this, or about 80 cfs per hour. Using the stage-discharge relationship for 3600 cfs, this would be a change of about 1.1 inches per hour at the site. Significant tributary inflow would probably have reduced the downramp effect at this location.

Over a 15-hour period during April 1998, the flow at Iron Gate dropped from 3850 to 2685, or 1155 cfs in 15 hours. Using a simplifying assumption of little tributary inflow, this would have been a stage change at the IFIM transect of about 14 inches. The decrease in wetted width from 3850 to 2685 cfs would be about 54 feet, about a 22% decrease. Changes in water surface and wetted width per 100 cfs are shown in Figure 13.

VII. CONCLUSIONS

1. PacifiCorp has accurate control over ramping at Iron Gate Dam at flows below 1735 cfs. Ramping at flows above 1735 cfs must be controlled at Copco, and the degree of control is much less.

2. Past ramping by PPL has nearly always met current license restrictions. It has also met generally-accepted agency guidelines for hourly downramping almost all the time.

3. During the Tree of Heaven event, major flow decreases (>2000 cfs) occurred over 1-3 day periods. The flows during this time exceeded the Iron Gate turbine capacity.

4. Empirical evidence for use in setting ramping rates below Iron Gate is lacking.

5. Results from the hydrodynamic model and from the pulse flow study suggest that the magnitude of a stage decrease per hour is reduced by about half at a distance of 50 miles from Iron Gate Dam. The variables affecting the zone of influence are total flow, ramp rate, and tributary inflow.

6. The existing data did not identify specific areas of potential stranding habitat. However, the amount of potential stranding habitat (e.g. side channels) appears to be less above vs. below the Shasta River.

7. Conditions that may lead to stranding are more likely to occur when flows are much greater than 1735 cfs at IGD. This is because IGD has no control at this range, and because water-level changes extend farther downstream at high flows.

VIII. REFERENCES

Ayres Associates. Geomorphic and Sediment Evaluation of the Klamath River, California, Below Iron Gate Dam. March 1999. Fort Collins, CO.

Deas, M.. and G. T. Orlob (1999). The Klamath River Modeling Project (Draft) Project No. 96-HP-01, funded by the Klamath River Basin Fisheries Task Force, administered by the United States Fish and Wildlife Service, Yreka Office. December.

Hanel, C. J. 1958, Calif. Dept. of Fish and Game. unpublished data.

Hunter, M.A. 1992. Hydropower flow fluctuations and salmonids: a review of the biological effects, mechanical causes, and options for mitigation. Tech. Report No. 119. Washington Department of Fisheries. Olympia, WA.

List of Tables and Figures:

Tables:

Table 1. Agency rules on ramping.

State of Washington		
Season	Daylight	Nighttime
Feb. 16 – June 15	None	2 inches/hour
June 16 – October 31	1 inch/hour	1 inch/hour
Nov. 1 – Feb. 15	2 inches/hour	2 inches/hour
State of California		
1. Based on natural ramping rates, if available 2. 10 – 15 % change in flow over 24 hour period		
State of Oregon		
1. Rule of thumb = 2 inches/hour 2. Monitor whether stranding is likely at 2 inches/hour 3. Individual cases: 0 – 2 inches/hour depending on season and time of day		

Table 2. Flow change to produce a 2 inch stage change at Iron Gate Dam, based on USGS rating table.

Flow Range	cfs to cause 2 inch stage change
6000	292
5000	225
4000	194
3000	163
2000	139
1900	139
1800	128
1700	128
1600	119
1500	119
1400	111
1300	111
1200	104
1100	104
1000	104

Table 3. Pulse flows from Iron Gate in 1994.

Date of pulse at Irongate	High flow (cfs)	Low Flow (cfs)
May 11 – May 16	1140	652
June 8 – June 10	1179	554

Table 4. Comparison of ramping at Iron Gate to flow changes at Seiad Gage (RM 123).

Date of pulse	Max change (cfs/hr)		Lag time (hrs)	Duration of pulse (hrs)	
	Irongate	*Seiad*		*Irongate*	*Seiad*
May 11 through May 18	61	27	66	55	96
June 8 through June 12	98	37	35	50	59

Table 5. Ramping trials with the hydrodynamic model

Trial	Starting flow cfs	Ending flow cfs	Flow decrease cfs/hour
1	3000	2000	250
2	1800	1300	100
3	1500	1000	100
4	1800	1300	250
5	1500	1000	250

Figures:

Klamath River Watershed Basemap

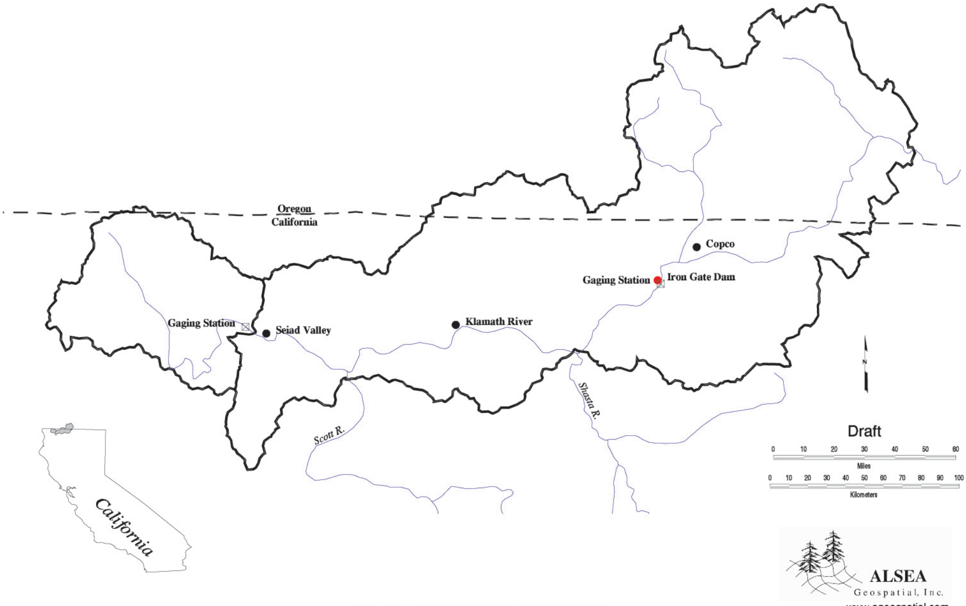


Figure 1: Study Area on the Klamath River

www.ageospatial.com
January 27, 2000

/u3/proj/iron/maps/basemap.aml

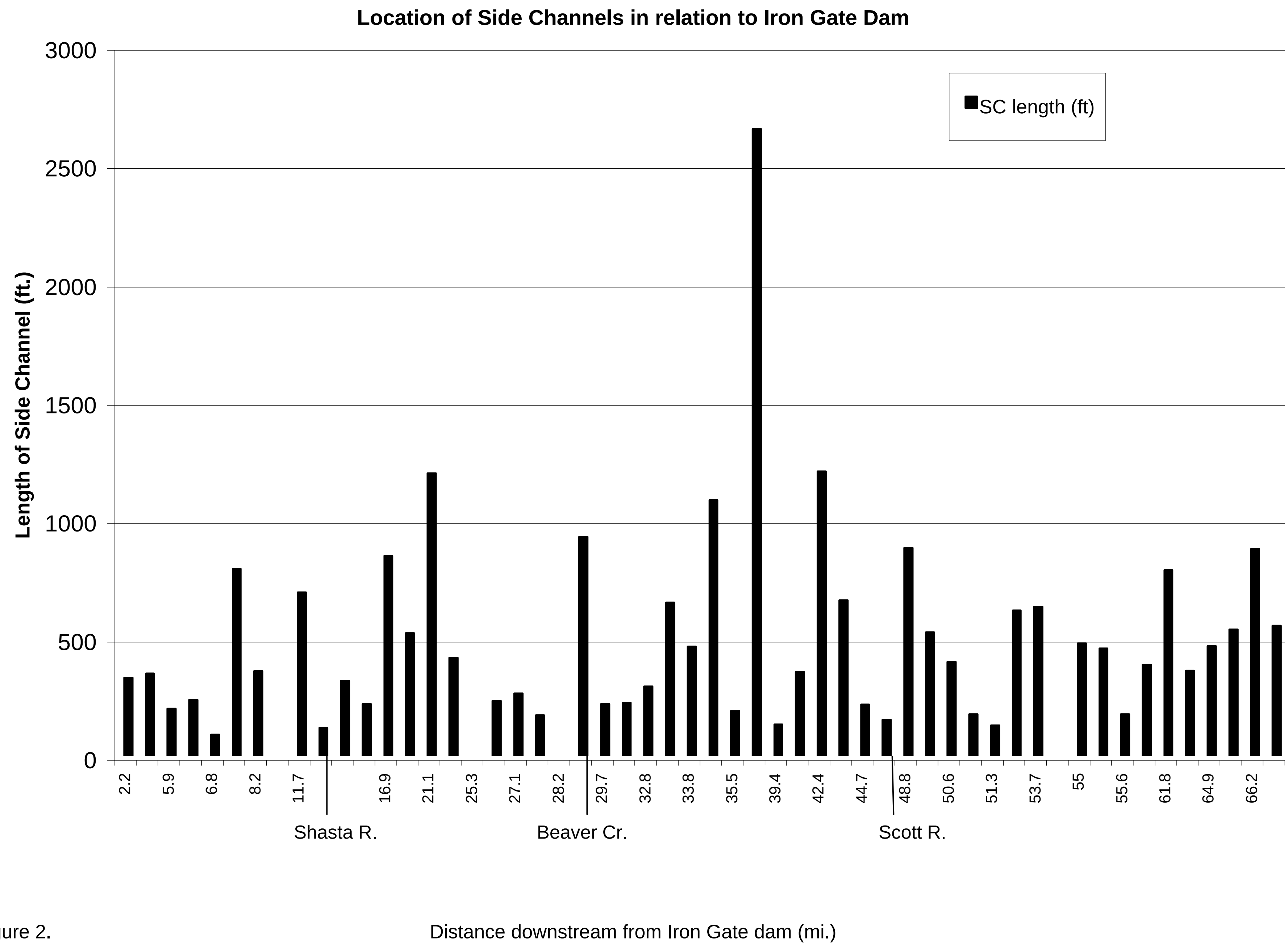
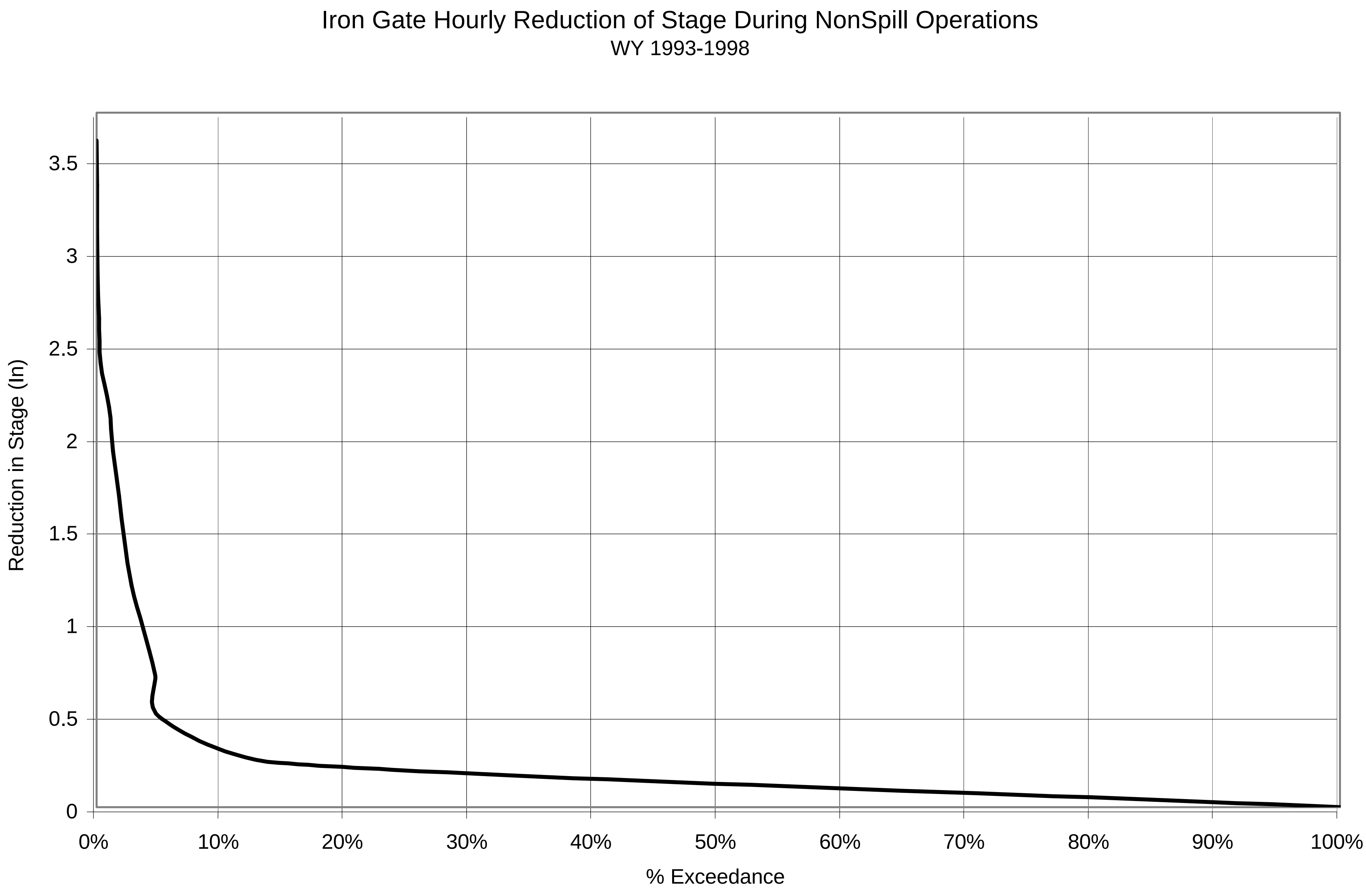

Location of Side Channels in relation to Iron Gate Dam
SC length (ft)
Length of Side Channel (ft.)
3000
2500
2000
1500
1000
500
0
2.2
5.9
6.8
8.2
11.7
16.9
21.1
25.3
27.1
28.2
29.7
32.8
33.8
35.5
39.4
42.4
44.7
48.8
50.6
51.3
53.7
55
55.6
61.8
64.9
66.2
Shasta R.
Beaver Cr.
Scott R.
Distance downstream from Iron Gate dam (mi.)

Figure 2.



Iron Gate Hourly Reduction of Stage During NonSpill Operations
WY 1993-1998
Reduction in Stage (In)
0
0.5
1
1.5
2
2.5
3
3.5
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Exceedance

Figure 3a.

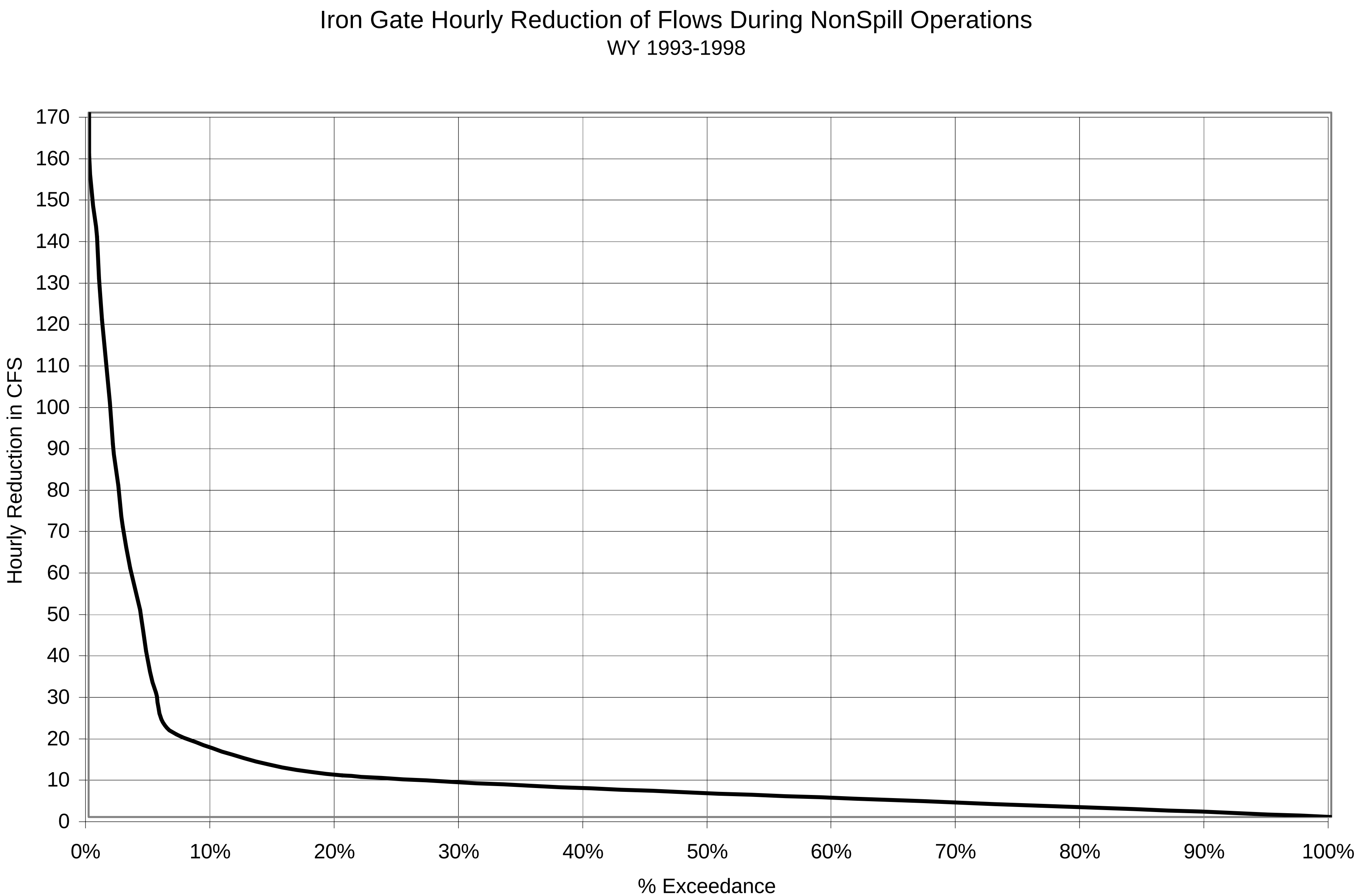

Iron Gate Hourly Reduction of Flows During NonSpill Operations
WY 1993-1998
Hourly Reduction in CFS
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Exceedance

Figure 3b.

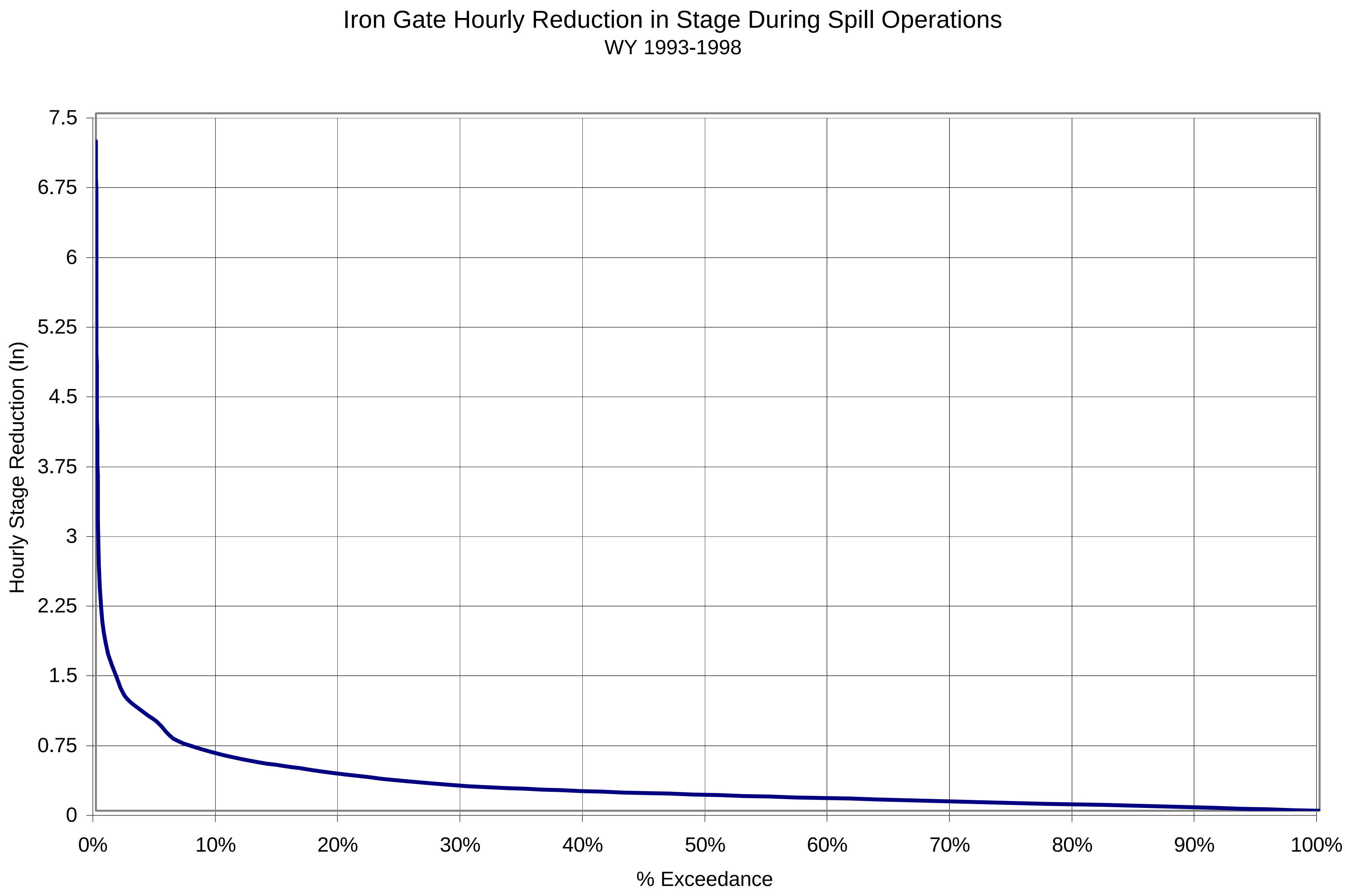

Iron Gate Hourly Reduction in Stage During Spill Operations
WY 1993-1998
7.5
6.75
6
5.25
4.5
3.75
3
2.25
1.5
0.75
0
Hourly Stage Reduction (In)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Exceedance

Figure 4a.

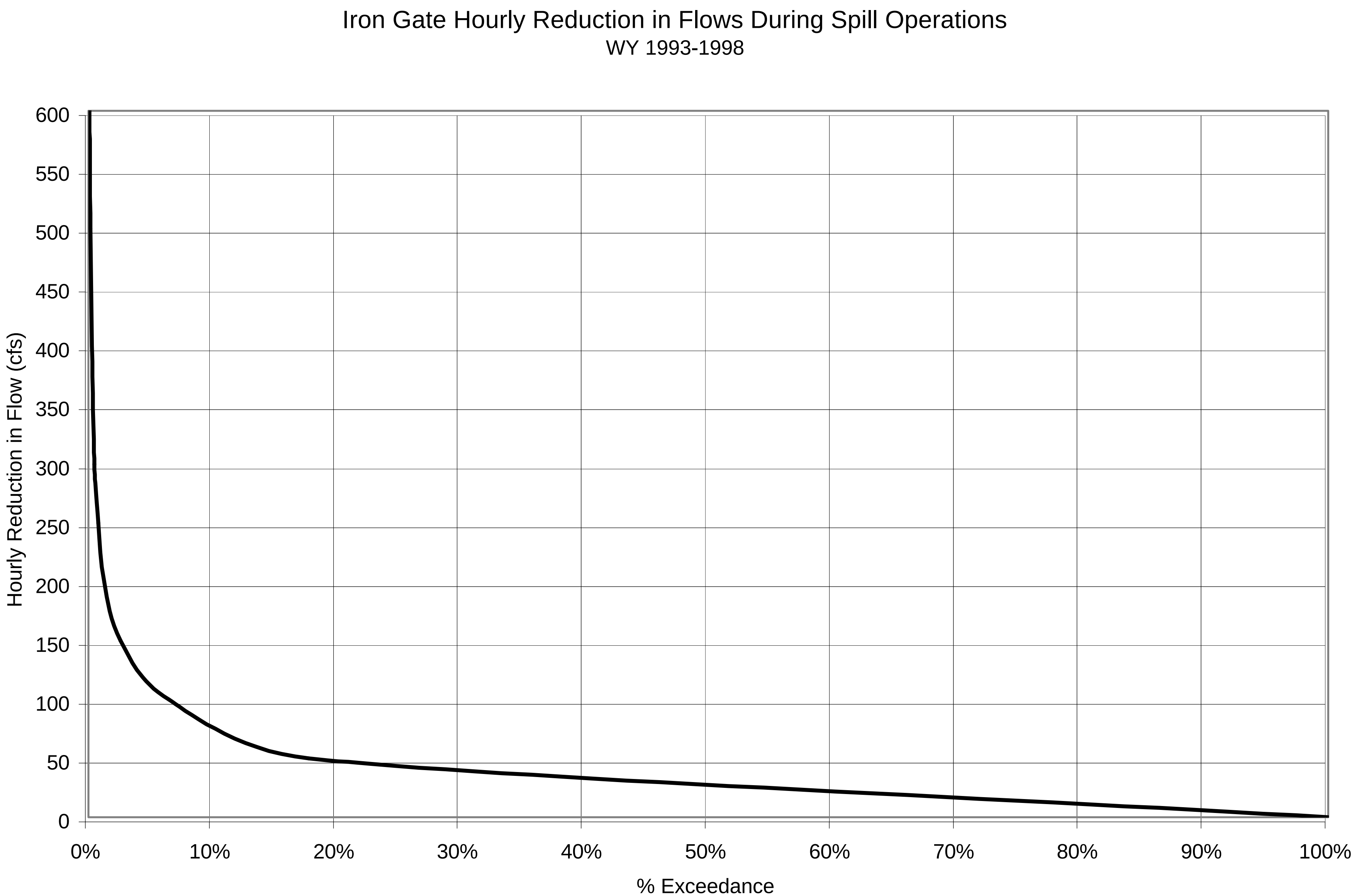

Iron Gate Hourly Reduction in Flows During Spill Operations
WY 1993-1998
Hourly Reduction in Flow (cfs)
600
550
500
450
400
350
300
250
200
150
100
50
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Exceedance

Figure 4b.

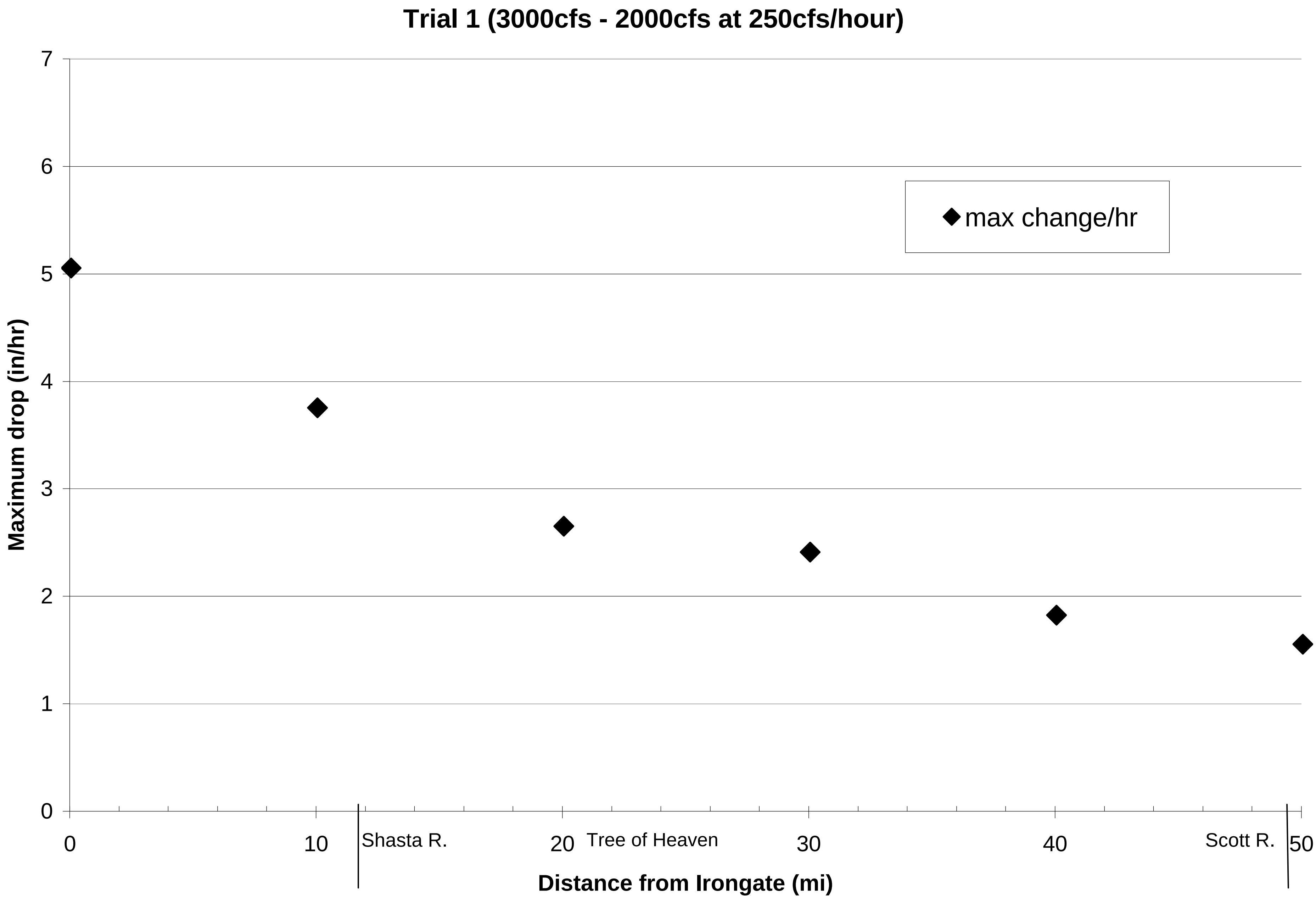


Figure 5. Maximum stage decrease per hour at 10 mile intervals below Iron Gate Dam, based on hydrodynamic model results.

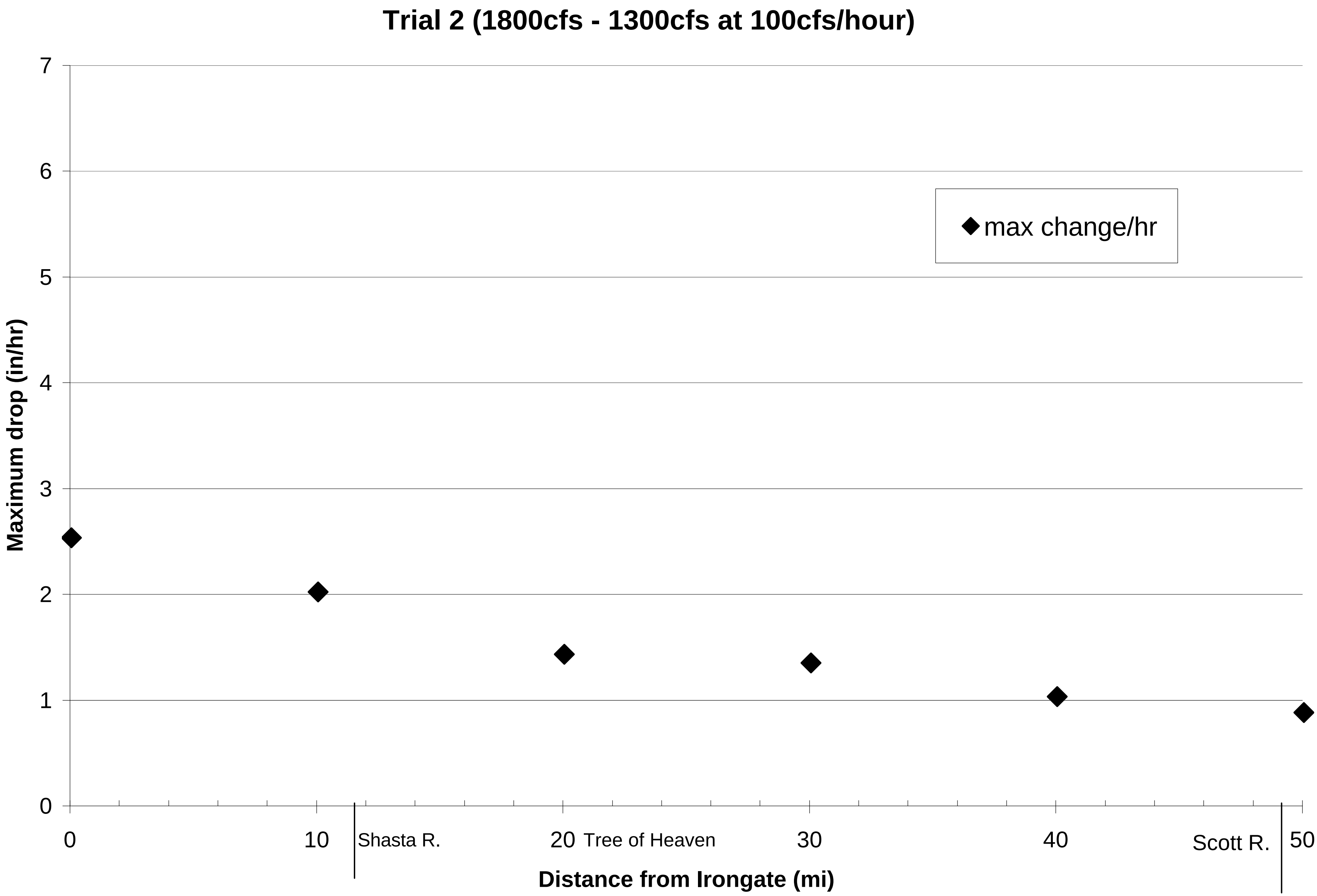


Figure 6. Maximum stage decrease per hour at 10 mile intervals below Iron Gate Dam, based on hydrodynamic model results.]

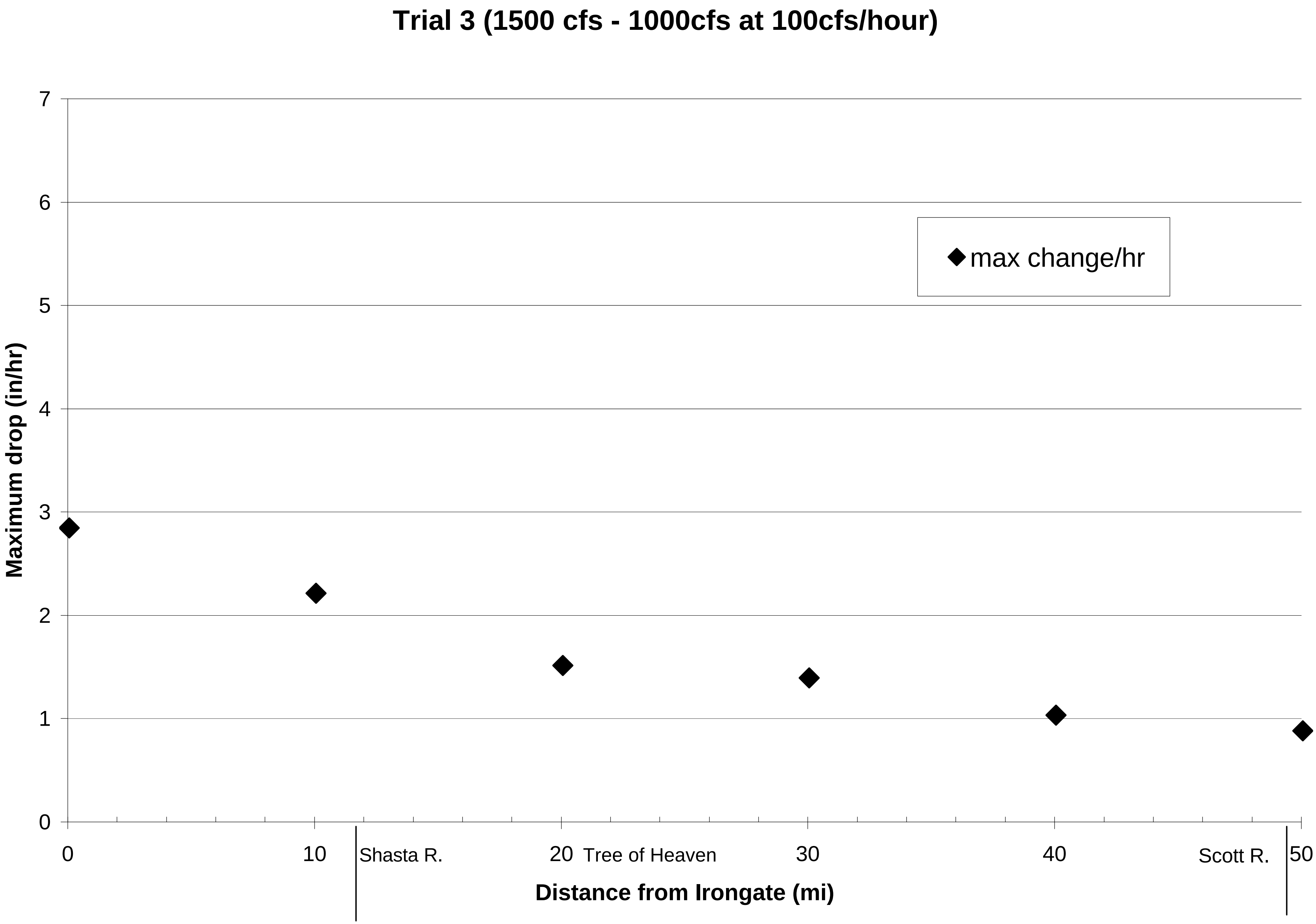


Figure 7. Maximum stage decrease per hour at 10 mile intervals below Iron Gate Dam, based on hydrodynamic model results.

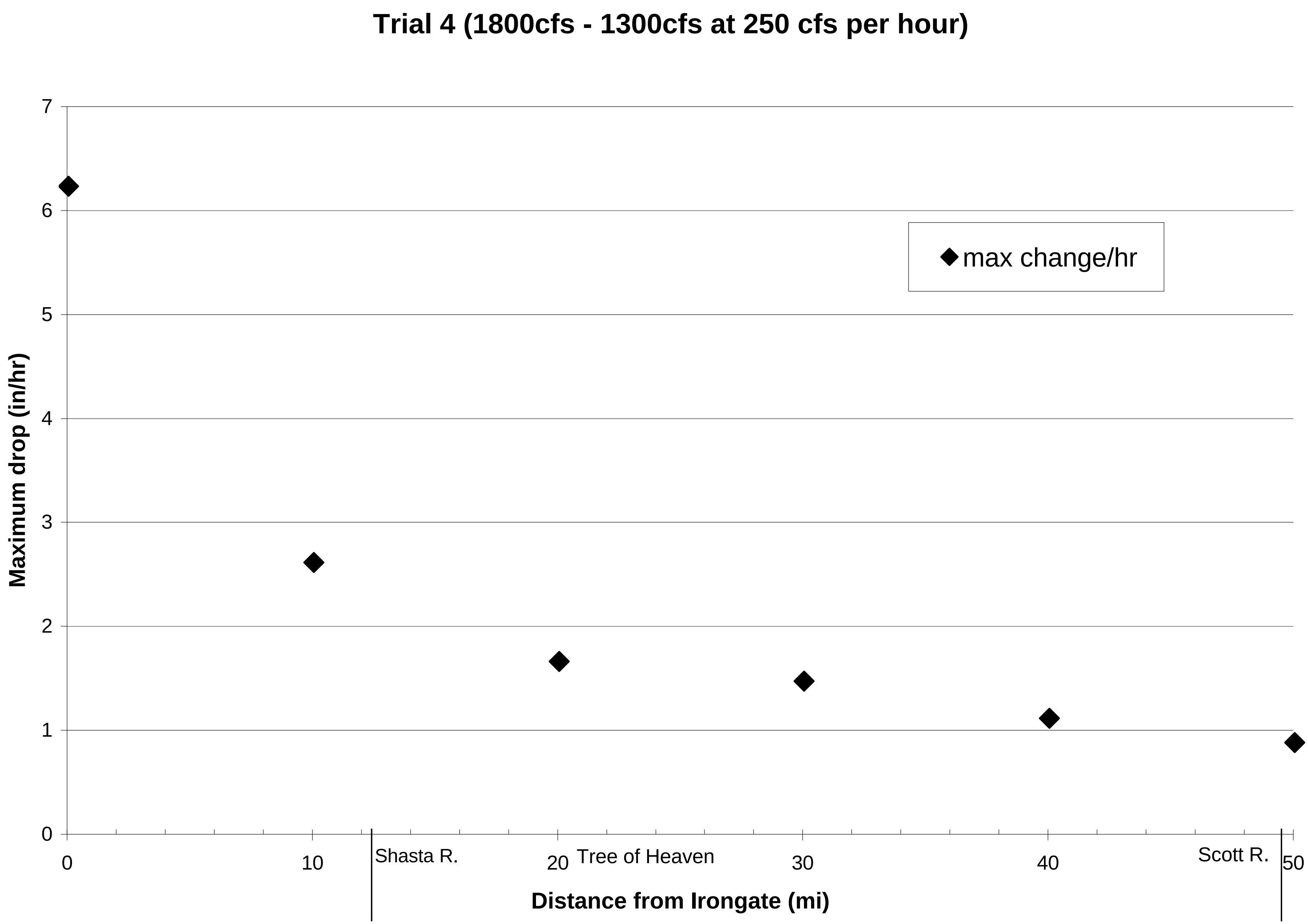


Figure 8. Maximum stage decrease per hour at 10 mile intervals below Iron Gate Dam, based on hydrodynamic model results.

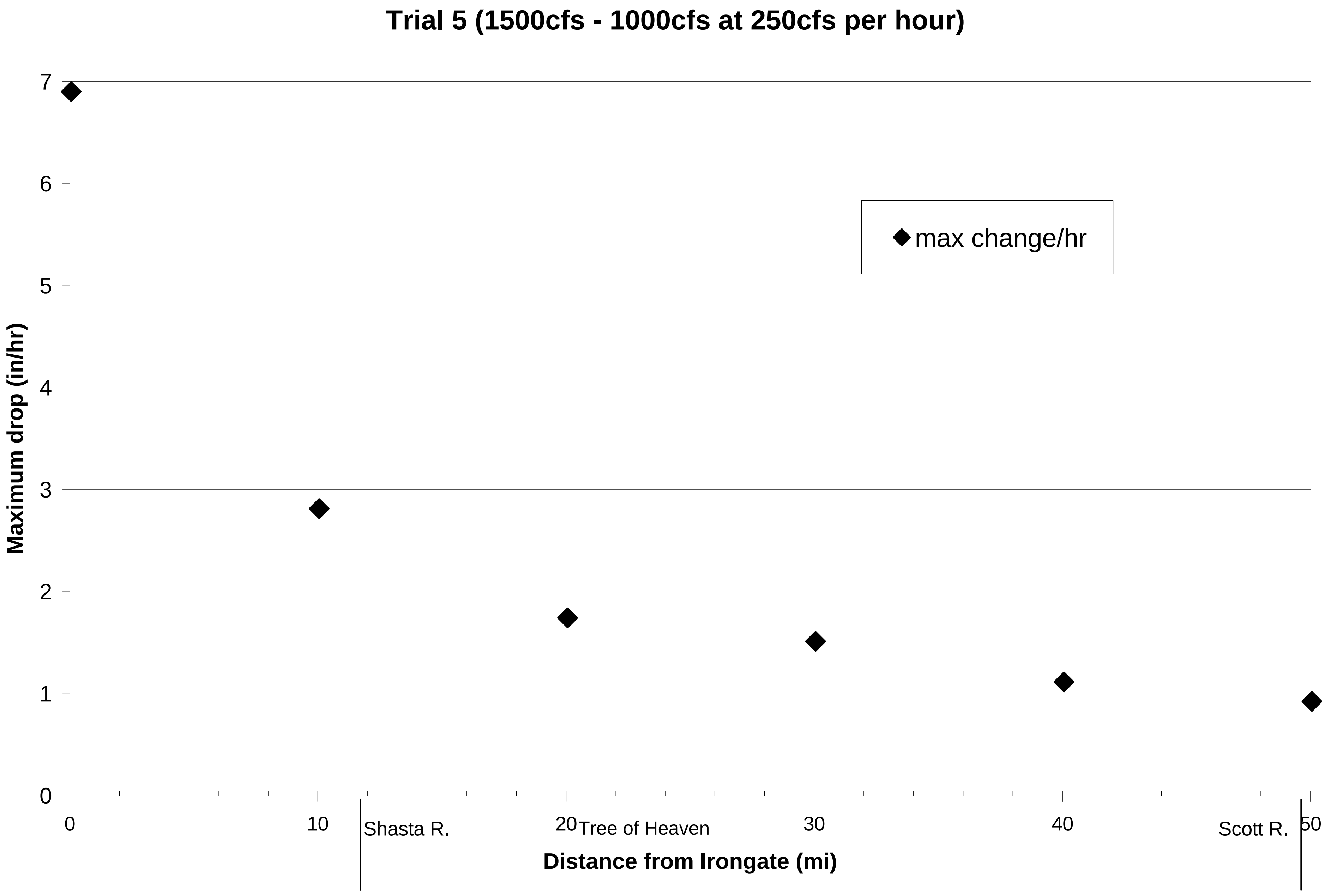


Figure 9. Maximum stage decrease per hour at 10 mile intervals below Iron Gate Dam, based on hydrodynamic model results.

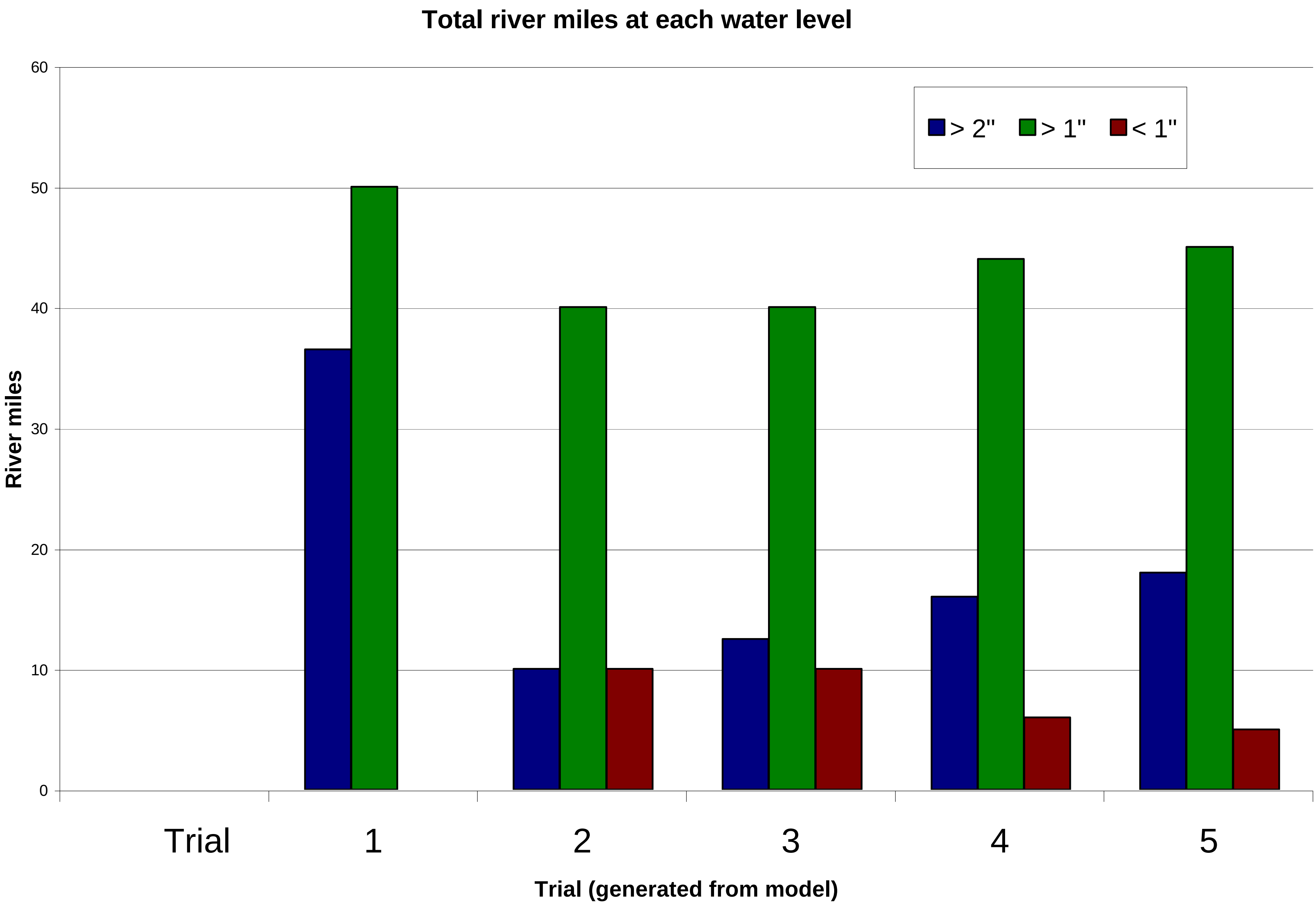


Fig. 10. Max stage decrease per hr. at 10 mi. intervals below Irongate dam, based on hydrodynamic model results. Trials: 1 (3000-2000, 250cfs/hr), 2 (1800-1300, 100cfs/hr), 3 (1500-1000, 100cfs/hr), 4 (1800-1300, 250cfs/hr), 5 (1500-1000, 250cfs/hr).

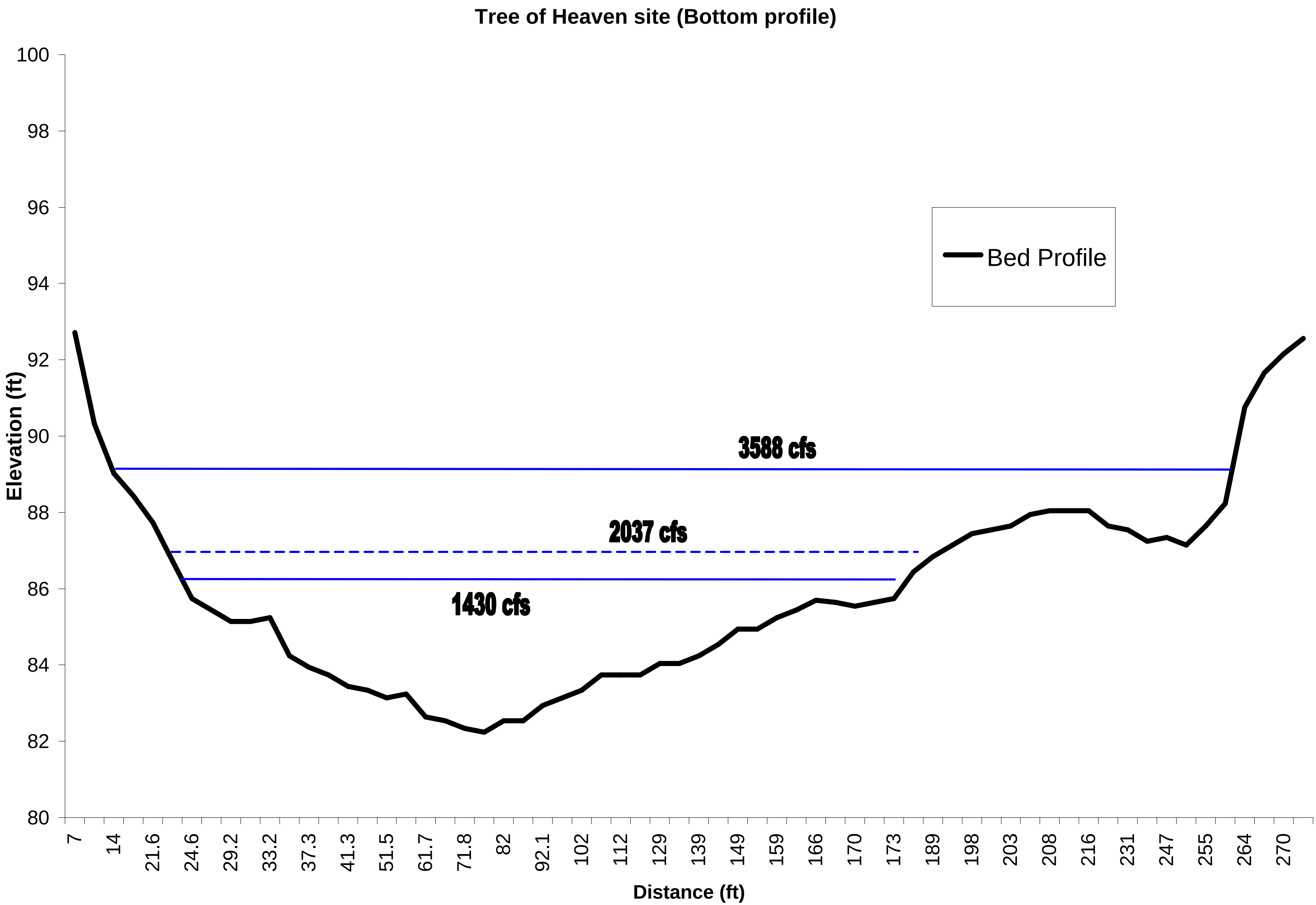


Figure 11. Cross-sectional profile and measured water surface elevations at Transect 1, Trees of Heaven IFIM site.

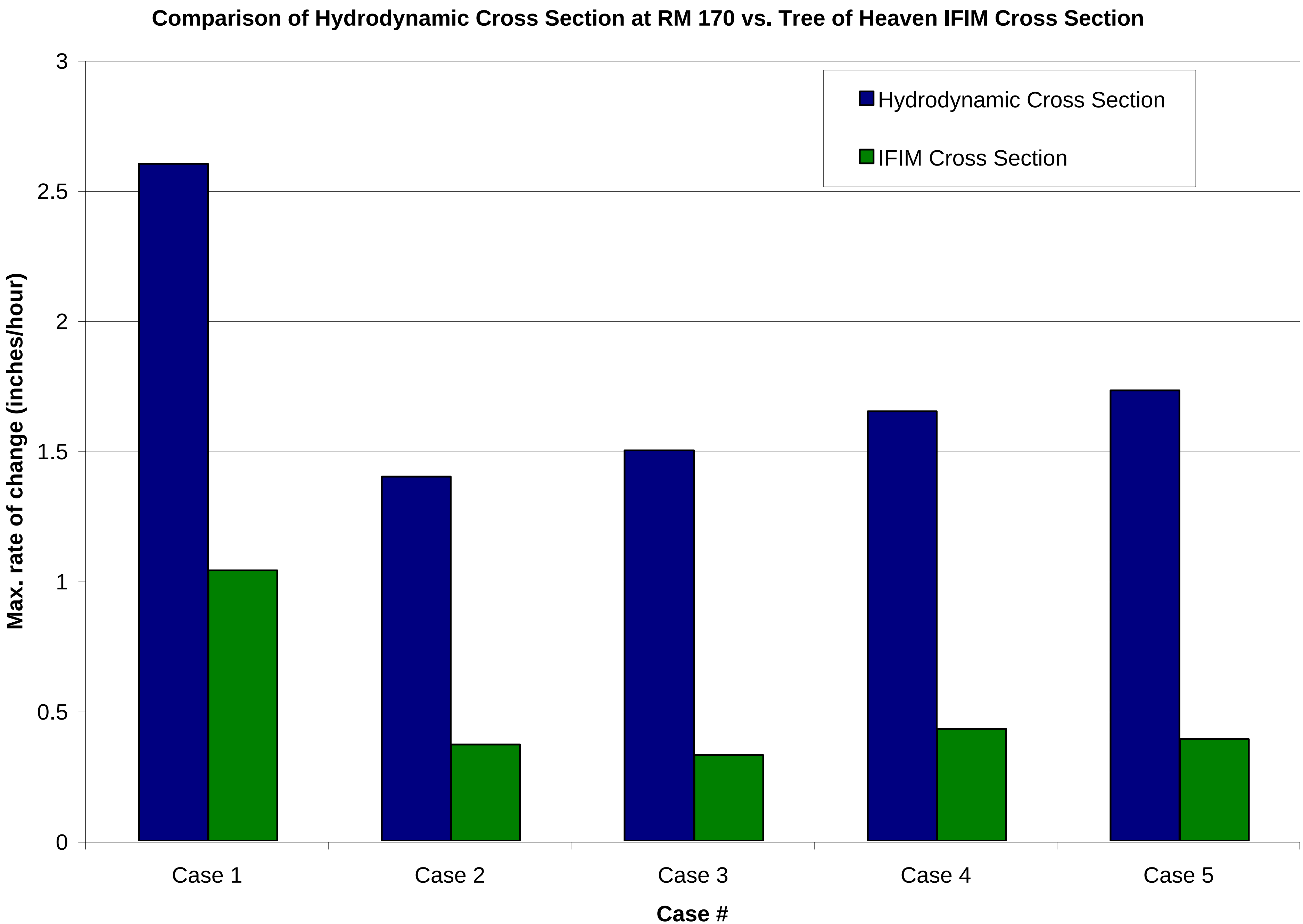
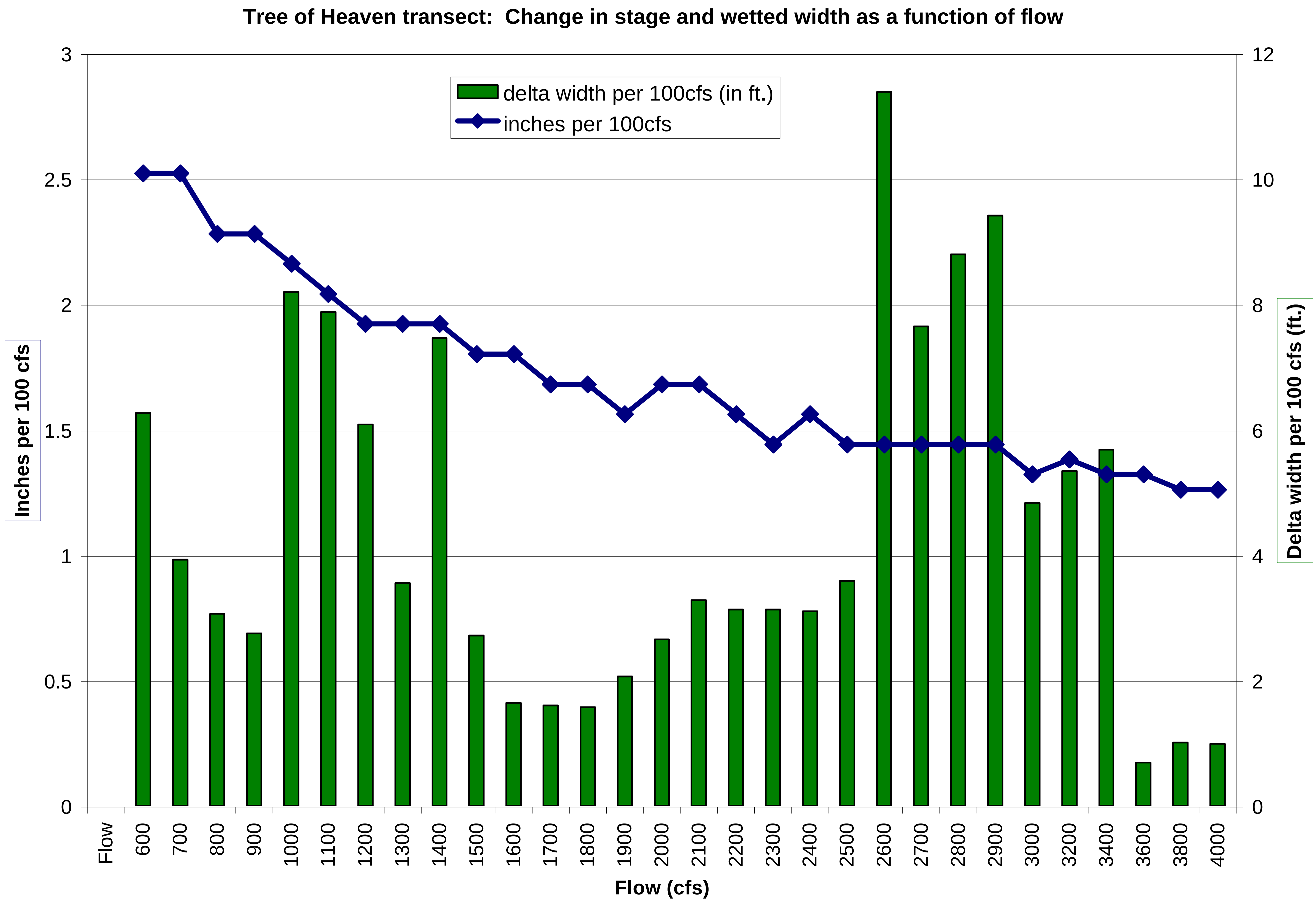

Comparison of Hydrodynamic Cross Section at RM 170 vs. Tree of Heaven IFIM Cross Section
Hydrodynamic Cross Section
IFIM Cross Section
Max. rate of change (inches/hour)
0
0.5
1
1.5
2
2.5
3
Case 1
Case 2
Case 3
Case 4
Case 5
Case #

Figure 12.



Tree of Heaven transect: Change in stage and wetted width as a function of flow
delta width per 100cfs (in ft.)
inches per 100cfs
Inches per 100 cfs
Delta width per 100 cfs (ft.)
Flow (cfs)
Flow
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3200
3400
3600
3800
4000
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10
12

Figure 13.